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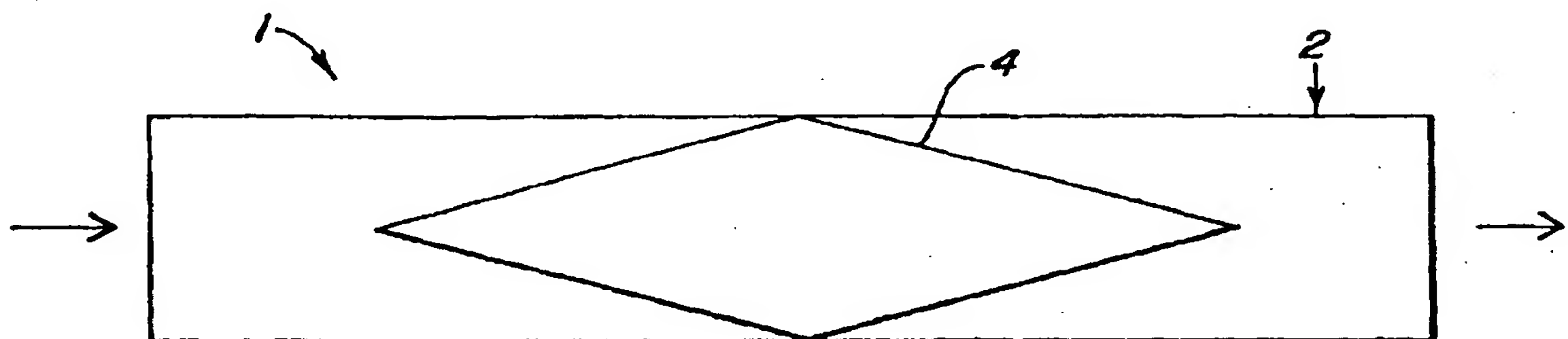
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(54) Title: LIGHT MODULATION USING THE FRANZ-KELDYSH EFFECT

Top View

(57) Abstract: An optical modulator includes at least one waveguide medium that receives light. An absorption medium absorbs the light under predefined conditions and outputs optically modulated light. The absorption medium is comprised of a Ge-based structure. The Ge-based structure uses the Franz-Keldysh effect to create said optically modulated light.

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LIGHT MODULATION USING THE FRANZ-KELDYSH EFFECT

PRIORITY INFORMATION

This application claims priority from provisional application Ser. No. 60/330,609
5   filed October 22, 2001.

BACKGROUND OF THE INVENTION

The invention relates to the field of optical modulator, and in particular to a method of modulating light in SiGe utilizing the Franz-Keldysh (FK) effect.

10   The FK effect states that the optical absorption of light in energy near the bandgap can be changed by the presence of an electric field. This effect has been utilized in direct gap systems, such as GaAs, to create electro-optic modulators, because the absorption coefficient changes very rapidly in the vicinity of the band edge. However, because phonons must be involved in absorption in an indirect transition,
15   absorption near the band edge is very weak in indirect semiconductors. Weak absorption makes them poor candidates for optical modulation. For this reason, the FK effect has not been effectively used to create electro-optic modulators in indirect semiconductors, such as Si or Ge.

Although Ge is an indirect semiconductor with a bandgap of approximately 0.68
20   eV, the direct transition lies at 0.8, which corresponds to 1.55um light. Ge is highly absorptive at 1.55 μm, so it cannot be used to make a modulator. However, the addition of Si raises the direction transition energy, creating a material with relatively low absorption.

The FK effect has been used in the InGaAs materials system to make linear
25   electro-absorption modulators. However, this effect has not been utilized in any Si-compatible materials system to make electro-optic modulators. Furthermore, the FK effect has not been used before in any system to make modulators utilizing a resonant structure or interference effect. Both of these applications are described in this invention.

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SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided an optical

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modulator. The optical modulator includes at least one waveguide medium that receives light. An absorption medium absorbs or transmits the light under predefined conditions and outputs optically modulated light. The absorption medium is comprised of a Ge-based structure. The Ge-based structure uses the Franz-Keldysh effect to create the

5 optically modulated light.

According to another aspect of the invention, there is provided a method of forming an optical modulator. The method includes providing at least one waveguide medium that receives light. The method also includes providing an absorption medium that absorbs the light under predefined conditions and outputs optically modulated light.

10 The absorption medium is comprised of a Ge-based structure. The method further includes using the Franz-Keldysh effect to produce the optically modulated light in the Ge-based structure.

BRIEF DESCRIPTION OF THE DRAWINGS

15 FIGs. 1A-1C are band diagrams demonstrating the improvements of the FK effect;

FIGs. 2A-2B are band structures for germanium and silicon;

FIG. 3 is an absorption spectrum of several semiconductors;

FIGs. 4A-4B are schematic diagrams of a linear waveguide modulator;

20 FIGs. 5A-5B are schematic diagrams of a ring resonator waveguide;

FIG. 6 is a schematic diagram of a Mach-Zehnder modulator structure;

FIGs. 7A-7C are graphs illustrating the absorption properties of a pure Ge structure using the FK effect; and

FIGs. 8A-8B are schematics of two structures that can be used to generate an

25 electric field in SiGe electro-optic modulators.

DETAILED DESCRIPTION OF THE INVENTION

The invention proposes a system and method of modulating light in Ge, SiGe, SiGeC, or other Ge-based materials utilizing the FK effect. This technique can be used

30 to modulate 1.55 μm light, but can also be used to modulate a range of frequencies, depending on the composition of the SiGe or Ge. If the absorption coefficient of a material can be changed, this can be used to modulate light. Specifically, if the

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absorption coefficient of a particular wavelength can be changed, then this effect can be used to design and create a modulator for this wavelength.

As stated hereinbefore, Ge is an indirect semiconductor with a bandgap of approximately 0.68 eV; the direct transition lies at 0.8 eV. Ge is highly absorptive at
5   1.55 μm. Adding Si raises the direct transition energy, creating a material with relatively low absorption at 1.55 μm. Then, by applying an electric field, absorption can be increased. In this way, the FK effect can be used in SiGe to modulate 1.55 μm light. This same effect could also conceivably be used in the same materials system to modulate 1.3 μm light.

10   FIGs. 1A and 1B are band diagrams associated with using the FK effect in SiGe or Ge. By applying an electric field, this increases the absorption. Using the FK effect on SiGe, this can form a modulator to modulate light at 1.55 μm. The concentration of Si will determine the band structure of the material, which in turn affects wavelengths to be modulated. By varying the composition, it should be possible to construct modulators
15   for a wide range of wavelengths.

FIG. 1A shows a band diagram associated with a SiGe or Ge structure where 1.55 μm light is not absorbed in absence of an electric field. The structure is not exposed to a high enough electric field to allow appreciable absorption. For valence electrons to reach the conduction band, it must tunnel through a triangular barrier height
20   $\mathcal{E}_g$ - hw and a thickness d, given by d = ($\mathcal{E}_g$ - hw)/qE. As E decreases, the barrier thickness, d, increases, reducing the tunneling probability and therefore reducing the absorption coefficient.

FIG. 1B shows an energy diagram associated with a SiGe or Ge structure where 1.55 μm light can be absorbed in the presence of an electric field. In this case, with the
25   aid of an absorbed photon that has energy less then the band gap, it can be shown that the barrier height is reduced to $\mathcal{E}_g - H\omega$ and the barrier thickness is reduce to d' = $\left(\mathcal{E}_g - H\omega\right)/qE$. If the electric field is high enough, the barrier thickness is short and the valence electron can tunnel to the conduction band. The FK effect can be thought of as photon-assisted tunneling.

30   The E field can be provided to the SiGe or Ge structure using either a p-i-n diode or a MOS capacitor structure. These are not the only possible structures for

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providing and electric field. Other structures for providing an electric field may also be conceived.

In the absence of an electric field, the above band diagram becomes flat and the barrier becomes infinite in width, as shown in FIG. 1C. Photons cannot be absorbed. The invention uses the FK effect to create a large change in the absorption coefficient near the direct transition, which is near the 1.55 μm light. Furthermore, by adding Si to a pure Ge structure, this increases the energy of the direct transition, thereby changing the wavelengths that can be modulated. Residual absorption from the indirect absorption would always be present in structures utilizing this effect.

For linear modulators a high change in the absorption coefficient is desirable to produce effective modulation in a short distance, and with the FK effect, the largest absolute change in absorption in a material can be achieved near the direct transition. The wavelengths modulated most effectively are those with energy near that of the direct transition.

In a linear modulator, a higher change in absorption coefficient will result in a shorter modulation length for a given modulation depth. If the change in absorption is smaller, a linear modulator with the same modulation depth will require a longer modulation length. There may be instances in which it is desirable for a linear modulator to have a small change in absorption coefficient and therefore corresponding longer modulating length. One example is in controlling optical chirp in the modulator.

This invention focuses on absorption changes near both the direct and indirect transitions, corresponding to large and small changes in the absorption coefficient, respectively.

It is possible to design a modulator, which operates using only a small change in the absorption. This allows light to be modulated using the FK effect in indirect absorption, where absorption is relatively weak.

In Ge or SiGe, absorption of light is weak near the band edge because phonons must be involved in the absorption process. However, a change in absorption can be achieved using the FK effect. By incorporating this small change in absorption in the proper structure, an effective modulator can be created.

There are three possible structures where a very small change in absorption coefficient can be used to modulate light. The first is in a resonant structure, which

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will be described more hereinafter. By increasing the absorption of the material by a small amount, the resonance of the structure can be destroyed. If designed properly, this can be used to modulate light. The second structure is a Mach-Zender (MZ) structure, which will be described more hereinafter. In this case, by changing the absorption in

5   one arms of the MZ structure, the interference between the light in the two arms can be changed, allowing for modulation of the outputted light. The third is a linear absorption modulator, where the change in absorption coefficient is small. As has been described hereinbefore, a smaller change in the absorption coefficient results in an increased absorption length for a given modulation depth. There may be instances where this is

10   desirable.

Also, the FK effect can be used with other material systems, such as InGaAs, to modulate 1.55 μm light. As with SiGe, by adjusting the composition, the band structure can be tailored to enable modulation of a range of wavelengths. The FK effect has been utilized in InGaAs systems to make modulators.

15   Moreover, the optical modulators using the inventive techniques can be used to create optical switches, thus making this technology applicable to other optical technologies.

FIGs. 2A-2B are band structures for germanium and silicon. The invention applies the FK effect to materials system compatible with Si processing. The FK effect

20   has been used to create electro-optic modulators in III-V compounds. However, no successful devices have been created in Si-compatible systems. One reason for this is that both Si and Ge have indirect band gaps. The FK effect is very weak near the band edge because of the indirect band gaps.

Another reason that the FK effect has not been used to modulate light in Si and

25   Ge is that their band gap energies are not near the energies of wavelengths of interest in optical communications. However, the direct transition energy of Ge is actually slightly smaller than the energy of 1.55 μm light, which makes it highly absorptive at this wavelength. Because the FK effect increases absorption, and the absorption coefficient of Ge is already high for 1.55 μm light, Ge has not been used in FK modulators.

30   The band structure of Si and Ge are described in more detail hereinafter.

FIG. 2A illustrates the band structure of germanium (Ge). The spin orbit splitting (s.o.) of the valence band at k=0 is shown. The band structure is spaced

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between $k = 2\pi/a\left(1/2,1/2,1/2\right)$ and $k = 2\pi/a\left(100\right)$. Also from FIG. 2A, the bandgap for Ge is approximately 0.66eV, and the direct transition is at 0.8 eV. There is a corresponding abrupt increase in the absorption coefficient at this energy. Thus, for energies greater than 0.8 eV, Ge behaves as a direct semiconductor. This can be seen in

5   FIG. 3 by the abrupt increase in absorption for wavelengths less than 1.5 μm, corresponding to energies less than 0.8 eV for Ge, which is the direct transition energy.

FIG. 2B illustrates the band structure of silicon (Si) near the band gap. The spin orbit splitting (s.o.) of the valence band at k=0 is shown. The band structure is spaced between $k = 2\pi/a\left(1/2,1/2,1/2\right)$ and $k = 2\pi/a\left(100\right)$. Also from FIG. 2B, the bandgap of

10   Si is at 1.08eV, and the direct transition is at 3.4 eV. In FIG. 3, it demonstrates a corresponding abrupt increase in the absorption coefficient at this energy corresponding to wavelengths shorter than 365nm. Thus, for energies greater than 3.4 eV, Si also behaves as a direct semiconductor.

FIG. 3 is an absorption spectrum of several semiconductors. In particular, FIG.

15   3 illustrates the absorption spectrum for semiconductors, such as Ge, GaAs, InP, GaP, Si, InGaAs, and $Ga_{0.3}In_{0.7}As_{0.64}P_{0.36}$. The bandgaps for GaP, GaAs, and InP are less than 1 μm, and the bandgap for Si is approximately between 1.0 μm and 1.2 μm. Moreover, the bandgap for $Ga_{0.3}In_{0.7}As_{0.64}P_{0.36}$ is approximately 1.4 μm, and for InGaAs is approximately 1.7 μm. Furthermore, the bandgap for Ge is approximately greater than

20   1.8 μm.

It can be seen that the absorption coefficient of a direct gap semiconductor increases very rapidly above the bandgap energy to a value of approximately $10^4/cm$. Changing the effective bandgap by means of the FK effect allows for large changes in the absorption coefficient near the band energy for direct gap semiconductors. For indirect

25   materials, such as Si, the absorption coefficient increases quadratically with energy above the band gap energy. The increase as a function of wavelength is much smaller than for direct gap semiconductors. A small shift in the effective band gap in an indirect semiconductor would not result in a very large change in the absorption coefficient at this energy, as compared to a direct gap semiconductor.

30   The invention proposes to modulate light absorption in Ge and SiGe using the FK effect near the direct transition. From FIG. 2A, the direct transition is at 0.8 eV.

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There is a corresponding abrupt increase in the absorption coefficient at this energy. Thus, for energies greater than 0.8 eV, Ge behaves as a direct semiconductor, as previously described.

Furthermore, the invention allows the modification of the direct transition energy by creating a SiGe alloy. By choosing the correct composition, a material can be created in which the bandgap is slightly higher in energy than the light to be modulated. Then, by application of an electric field, the light can be selectively absorbed or transmitted through the device.

FIGs. 4A-4B are schematic diagrams of a linear waveguide modulator. FIG. 4A illustrates a side view of the linear waveguide modulator 1. The linear waveguide modulator 1 includes a linear waveguide 2 that is coupled into a SiGe waveguide 4. The SiGe waveguide 4 forms a variable absorption region for modulation of light received by the linear waveguide modulator 1. The SiGe waveguide 4 uses the FK effect to modulate light. The waveguide 4 can also be constructed using other Ge-based structures, which can use the FK effect for modulating light.

FIG. 4B is a top view of the linear waveguide modulator 1. The SiGe waveguide 4 has a patterned shaped to specifically absorb light of a specify wavelength. Other patterned shapes can be used to accomplish the same task. The change in the absorption coefficient of a particular wavelength of SiGe provides the flexibility to design and create the SiGe waveguide 4, thus forming the linear waveguide modulator for this wavelength.

In the off state, the light passes into the SiGe waveguide 4, and then back out to the linear waveguide 2. In the on state, the SiGe waveguide 4 absorbs the vast majority of the light to the output, via the linear waveguide 2. The patterned shape of the SiGe waveguide 4 determines the amount of time that light can be absorbed of a specified wavelength.

FIGs. 5A-5B are schematic diagrams of a ring resonator waveguide. A ring resonator waveguide 6, as shown in FIGs. 5A and 5B, includes a ring resonator 8 that can be turned on and off to   ple light into one of two waveguides 10 and 12.

FIG. 5A demonstrates the ring resonator waveguide 6 in an off state. In this state, the ring 8 is non-absorbing and light is coupled into the waveguide 10. FIG. 5B demonstrates an on state of the ring resonator waveguide 6. In this

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arrangement, the ring 8 absorbs the light, preventing the resonant build up of light in the ring 8. As a consequence, light is not coupled into waveguide 10 and continues traveling in the waveguide 12, as shown by the direction of the light in the waveguide 12. This device can be used as either an optical modulator or an optical switch.

5   Since a relatively small amount of absorption will kill the resonance in the ring 8, the composition for the ring 8 will have a Si content such that only a small amount of absorption will be induced by the FK effect. Light is modulated near the indirect band edge, turning on and off the indirect absorption in the material. Another alternative is to have a thin SiGe layer either above or below the non-absorbing ring 8. Only a small part

10   of the mode will travel in the SiGe thin layer, and by modulating the absorption of this thin layer, the resonance of the structure will be affected.

FIG. 6 is a schematic diagram of a Mach Zehnder (MZ) structure 14. This structure can be used to modulate light by changing the phase of the light in one or both arms 16 and 18 of the MZ structure 14. Light is inputted into the structure 14 by means

15   of a waveguide 20, and is then divided evenly between the two arms 16 and 18 of the MZ structure 14. If the light from the two arms 16 and 18 are in phase with each other, light will be outputted from the structure 14. If the light from the two arms 16 and 18 are out of phase with each other, the light will destructively interfere, and no light will be outputted.

20   By constructing the waveguide regions in one or both arms 16 and 18 of the MZ structure 14 out of SiGe, the absorption coefficient of the structure can be modified by means of the FK effect. Because a change in the absorption coefficient will also cause a change in the phase of the light outputted from the structure 14, this can be used effectively to modulate light as described above. To induce a phase change, only a small

25   change in the absorption is needed. The arms 16 and 18 can also be constructed using other Ge-based materials that are operable using the FK effect for optical modulation.

Because only a small change in absorption is needed, the composition of the waveguide region in the MZ arms 16 and 18 will have a SiGe content such that only a small amount of absorption will be induced by the FK effect.

30   FIG. 7A-7C are graphs illustrating the absorption properties of a pure Ge structure using the FK effect. When a change in the absorption coefficient is introduced a change in the index of refraction also occurs. In the case of the MZ structure 14

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described above, the change in the refractive index changes the phase of the light, allowing constructive or destructive interference between the light from the two arms 16 and 18 of the modulator 14. The constructive and destructive interference results in the modulation of the light. Thus, the FK effect not only affects the absorption coefficient, but also affects other properties, such as the index of refraction. The FK effect can be used to create a modulator by modifying these properties as well.

FIG. 7A is a graph illustrating the change in the index of refraction as a function of wavelength for an electric field of 100 kV/cm in pure Ge. As the wavelength is increased above 1580 nm, the index of refraction is also increased.

The k-value of an electric field can be a function of wavelength for an electric field, and is related to the absorption coefficient α, by the relation $k = \alpha\lambda/(4\pi)$. FIG. 7B is a graph illustrating the changes of the k-value as a function of wavelength for an electric field of 100 kV/cm in pure Ge. Furthermore, FIG. 7C is a graph illustrating the change of absorption coefficient as a function of the electric field and energy in pure Ge. These graphs illustrate the various factors that can change the absorption of a particular structure, such as pure Ge.

FIGs. 8A-8B are schematics of two structures 24 AND 32 that can be used to generate an electric field in SiGe electro-optic modulators. The first is a p-i-n structure 24 of FIG. 8A, and the second is a MOS structure 32 of FIG. 8B. Both of these structures 24 and 32 are widely used in current semiconductor processing. Other possible structures can be used to apply an electric field in an electro-optic modulator to utilize the FK effect.

The SiGe p-i-n structure 24 depicted in FIG. 8A is one possible embodiment of such a structure, and includes an n contact 26, p contact 30, and a layer of SiGe 28. This is not the only way in which such a structure can be made with SiGe. For example, the n 26 and p 30 contacts can be reversed. In this embodiment, the SiGe layer 28 is epitaxially grown on top of a p-doped Si substrate 30. On top of the SiGe layer, the n-doped poly Si 26 is deposited. Many methods could be used to make such a device, and other materials can be incorporated or substituted as well.

Furthermore, the structure 24 has a built in electric field. By applying an electrical bias to the structure, the electric field is changed, thus changing the electro-optic properties of the SiGe region 28 by   means of the FK effect. In this

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embodiment the p-i-n structure 24 forms part of a waveguiding region for the light, with light entering on the left and exiting on the right. This structure 24 can be a part of an electro-optic modulator structure, as those described herein.

The SiGe MOS structure 32 depicted in FIG. 8B is another possible embodiment
5   for providing electric fields, and includes an n contact A that is comprised of n-poly materials, a SiO2 layer 36, a SiGe layer 38, and a contact B that is comprised of a P-silicon substrate. Other possible arrangements can be used to form the SiGe MOS structure 32, for example, an insulating material other than SiO_2 can be used as the insulating layer or an n doped Si substrate can also be used.

10   In this embodiment, the SiGe layer 38 is epitaxially grown on top of a p-doped Si substrate 40. On top of the SiGe layer 38, a layer 36 of insulating SiO2 is grown. A layer 34 of n-doped poly Si is grown on the SiO_2 layer. Several methods are available for depositing the top two layers 36 and 38. Deposition processes must be chosen that will result in high quality layers and interfaces between layers in order that the device
15   function properly.

By applying a voltage between the two contacts A and B, an electric field can be introduced in the SiGe region 38. Adjusting the voltage can control the magnitude of the electric field. In this way, the electro-optic properties of the SiGe region 38 can be changed by means of the FK effect. Also, the SiGe MOS structure 32 forms part of a
20   waveguiding region for light, with light entering on the left and exiting on the right. This structure 32 can be part of an electro-optic modulator structure, as those described herein.

Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the
25   form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

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CLAIMS

1   1. An optical modulator comprising:

2   at least one waveguide medium that receives light; and

3   an absorption medium that absorbs said light under predefined conditions and

4   outputs optically modulated light, said absorption medium is comprised of a Ge-based

5   structure; wherein

6   said Ge-based structure uses the Franz-Keldysh effect to create said optically

7   modulated light.

1   2. The optical modulator of claim 1, where said Ge-based structure is comprised of

2   SiGe.

1   3. The optical modulator of claim 1, wherein said Ge-based structure is comprised pure

2   Ge.

1   4. The optical modulator of claim 1, wherein said wavelength is 1.55 μm or 1.3um.

1   5. The optical modulator of claim 1, wherein said at least one waveguide medium

2   comprises a linear waveguide structure.

1   6. The optical modulator of claim 1, wherein said absorption medium comprises a

2   patterned SiGe waveguide using said Franz-Keldysh effect.

1   7. The optical modulator of claim 1, wherein said at least waveguide structure comprises
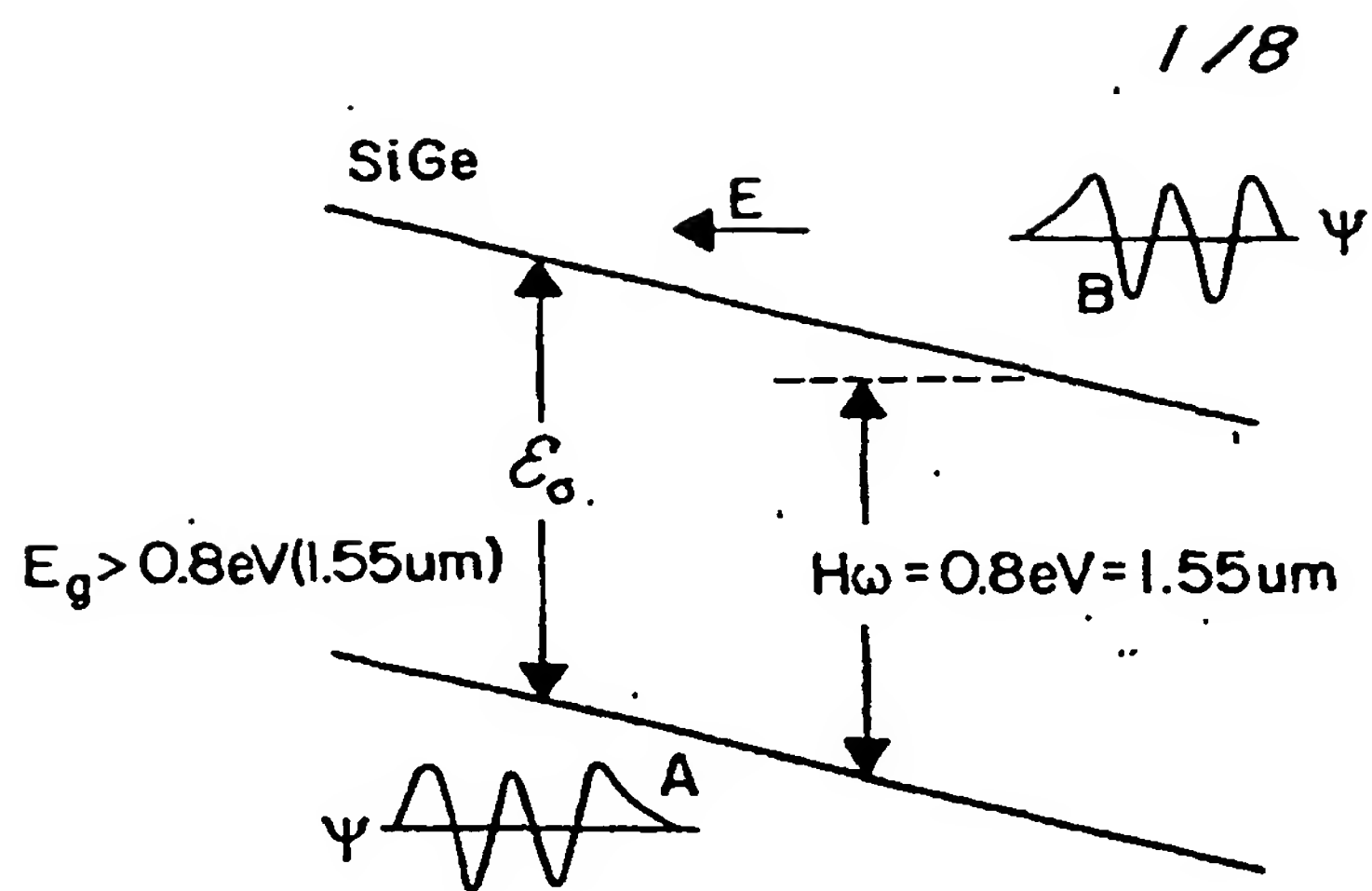
2   two waveguides.

1   8. The optical modulator of claim 7, wherein said absorption medium is a ring resonator

2   structure.

1   9. The optical modulator of claim 1, wherein said absorption medium is in one or both

2   arms of a Mach-Zender structure.

1   10. The optical modulator of claim 1, wherein said predefined condition comprises an

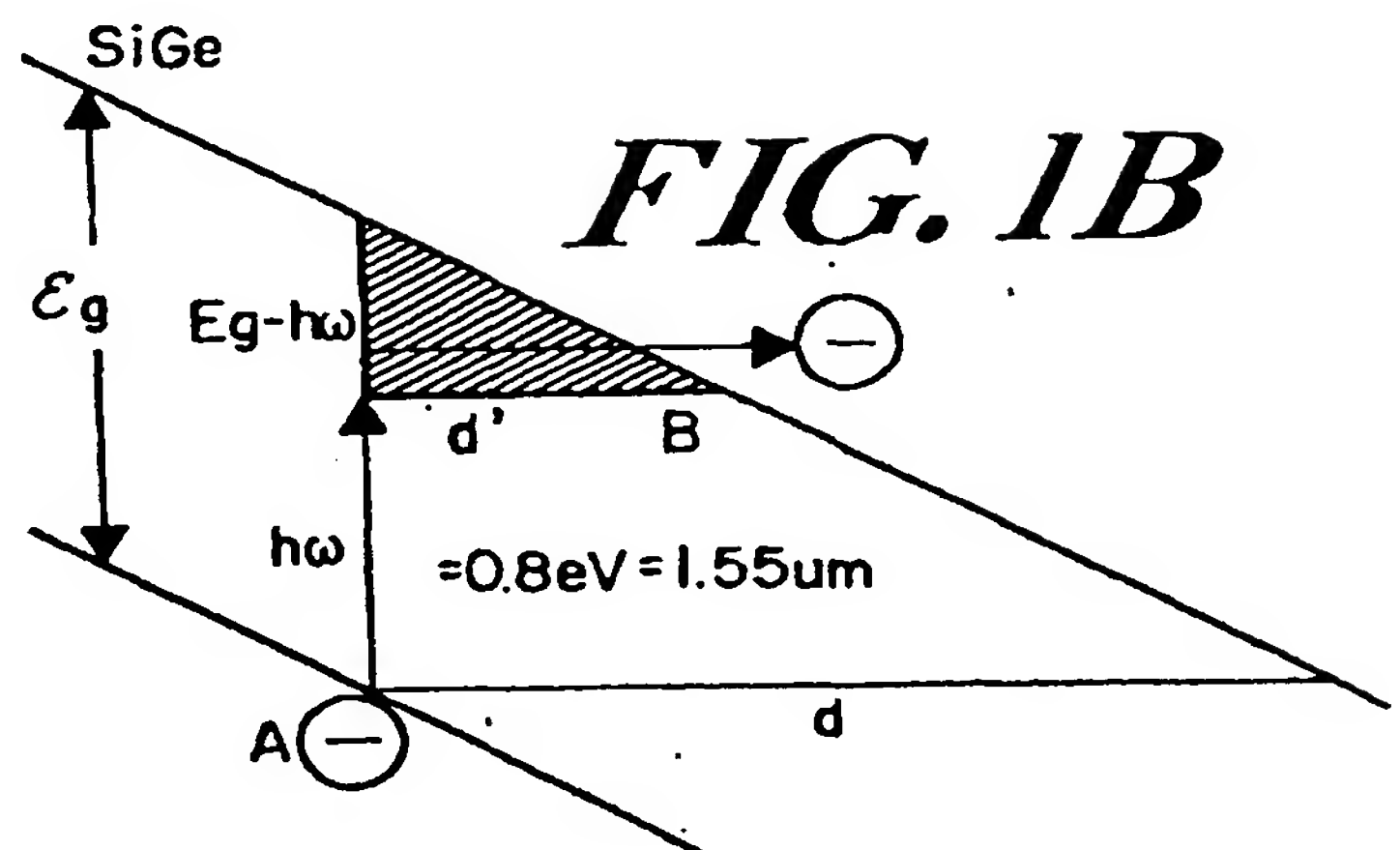2   off state, where said light is not absorbed by said absorption medium.

1   11. The optical modulator of claim 10, wherein   said   predefined   condition

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2   comprises an on state, where said light is absorbed by said absorption medium.

1   12. A method of forming an optical modulator comprising:

2   providing at least one waveguide medium that receives light;

3   providing an absorption medium that absorbs said light under predefined

4   conditions and outputs optically modulated light, said absorption medium is comprised of

5   a Ge-based structure, and

6   using the Franz-Keldysh effect to produce said optically modulated light in said

7   Ge-based structure.

1   13. The method of claim 12, where said Ge-based structure is comprised of SiGe.

1   14. The method of claim 1, wherein said Ge-based structure is comprised of pure Ge.

1   15. The method of claim 12, wherein said wavelength is 1.55 μm or 1.3um.

1   16. The method of claim 12, wherein said at least one waveguide medium comprises a

2   linear waveguide structure.

1   17. The method of claim 12, wherein said absorption medium comprises a patterned

2   SiGe waveguide using said Franz-Keldysh effect.

1   18. The method of claim 12, wherein said at least waveguide structure comprises two

2   waveguides.

1   19. The method of claim 18, wherein said absorption medium is a ring resonator

2   structure.

1   20. The method of claim 12, wherein said predefined condition comprises an off state,

2   where said light is not absorbed by said absorption medium.

1   21. The method of claim 20, wherein said predefined condition comprises an on state,

2   where said light is absorbed by said absorption medium.

1   22. The method of claim 12, wherein said absorption medium is in one or both arms of
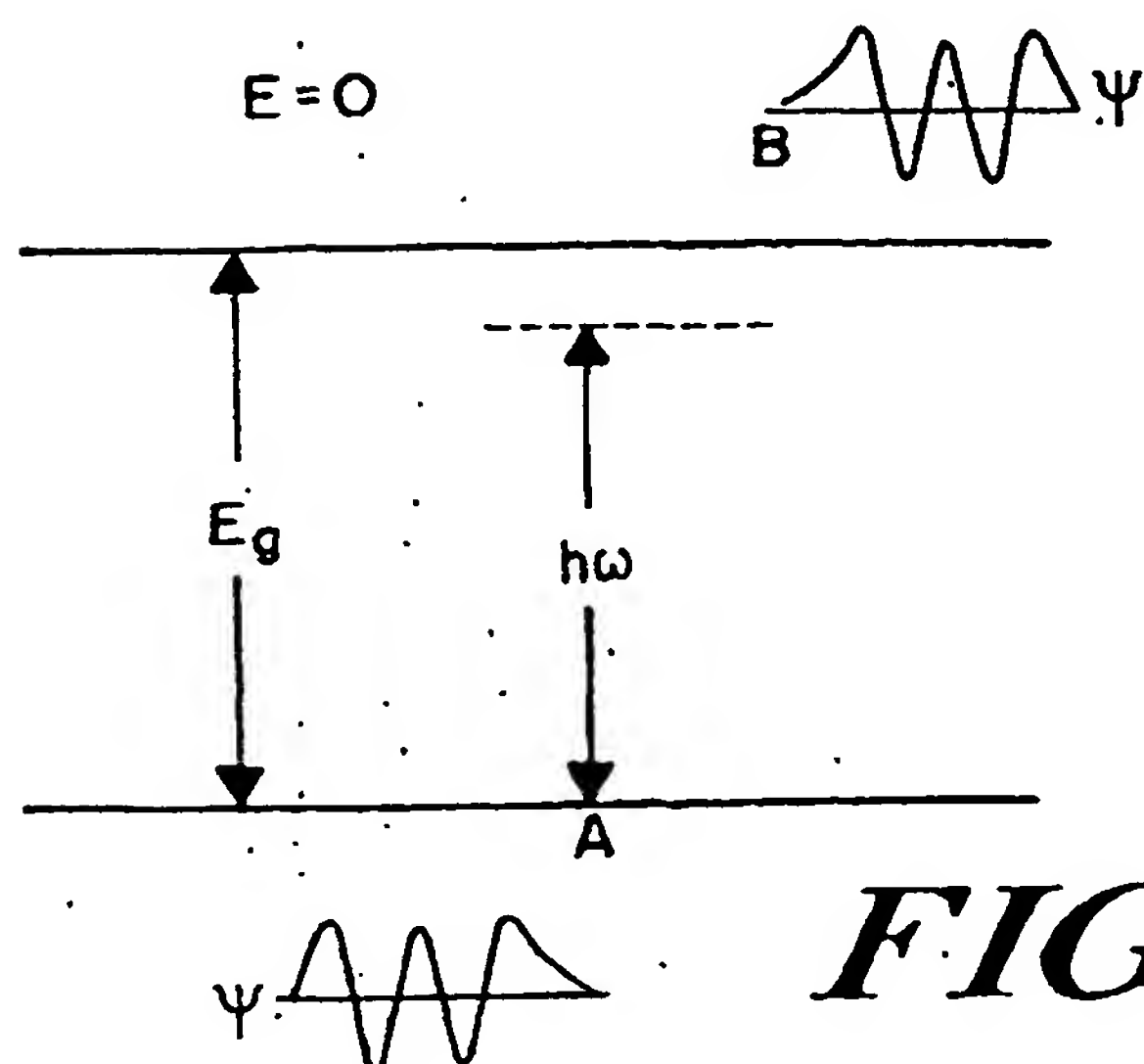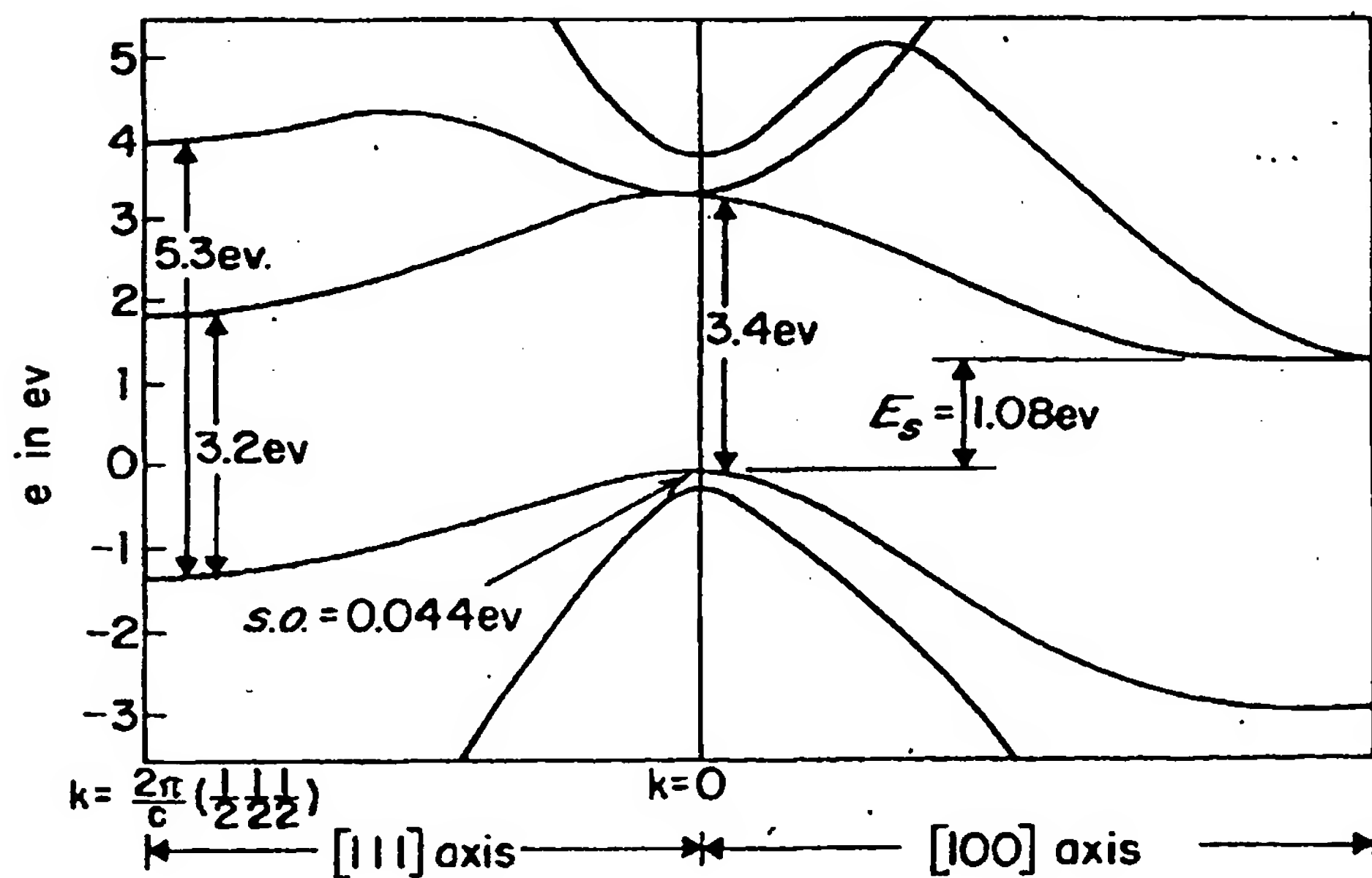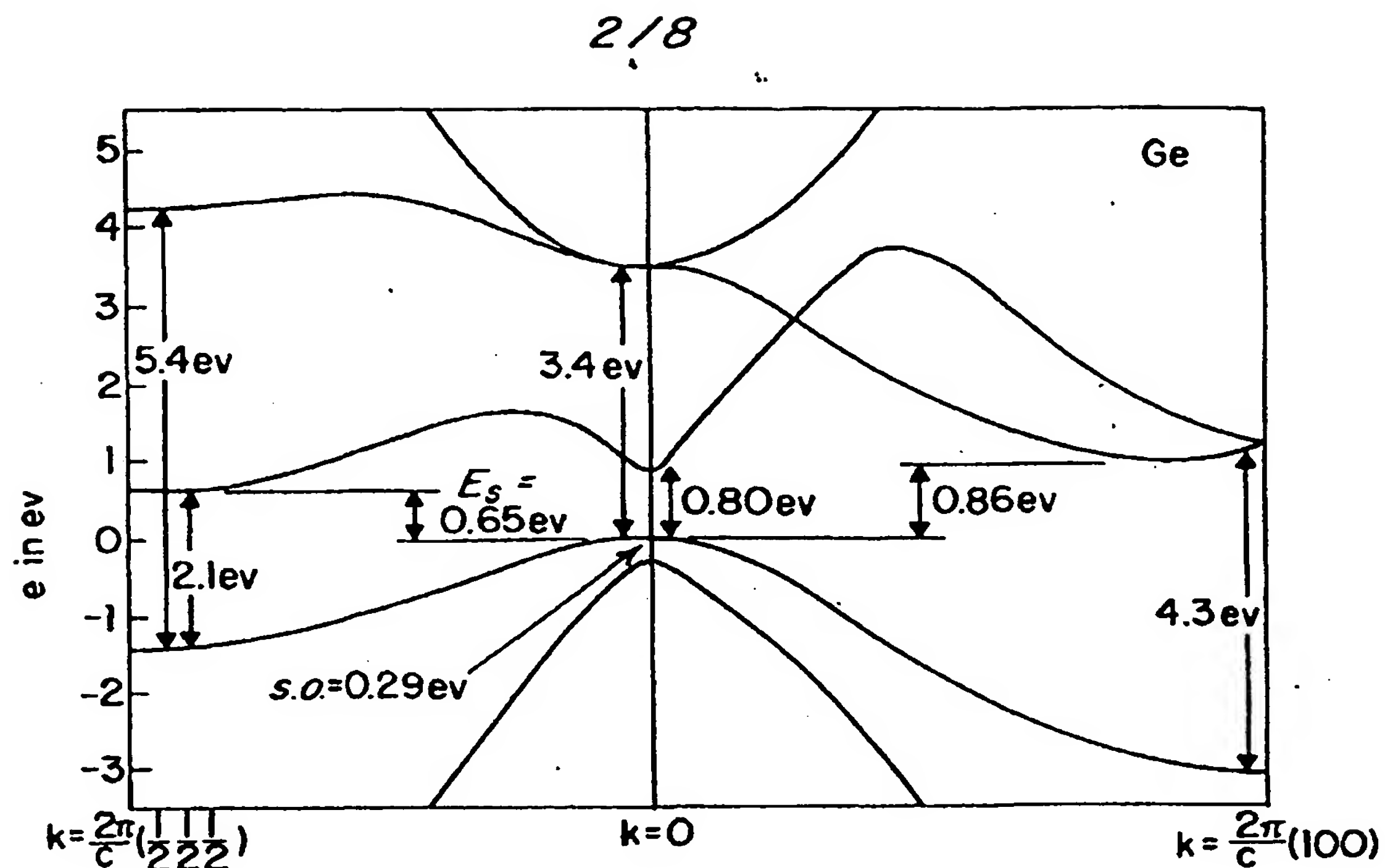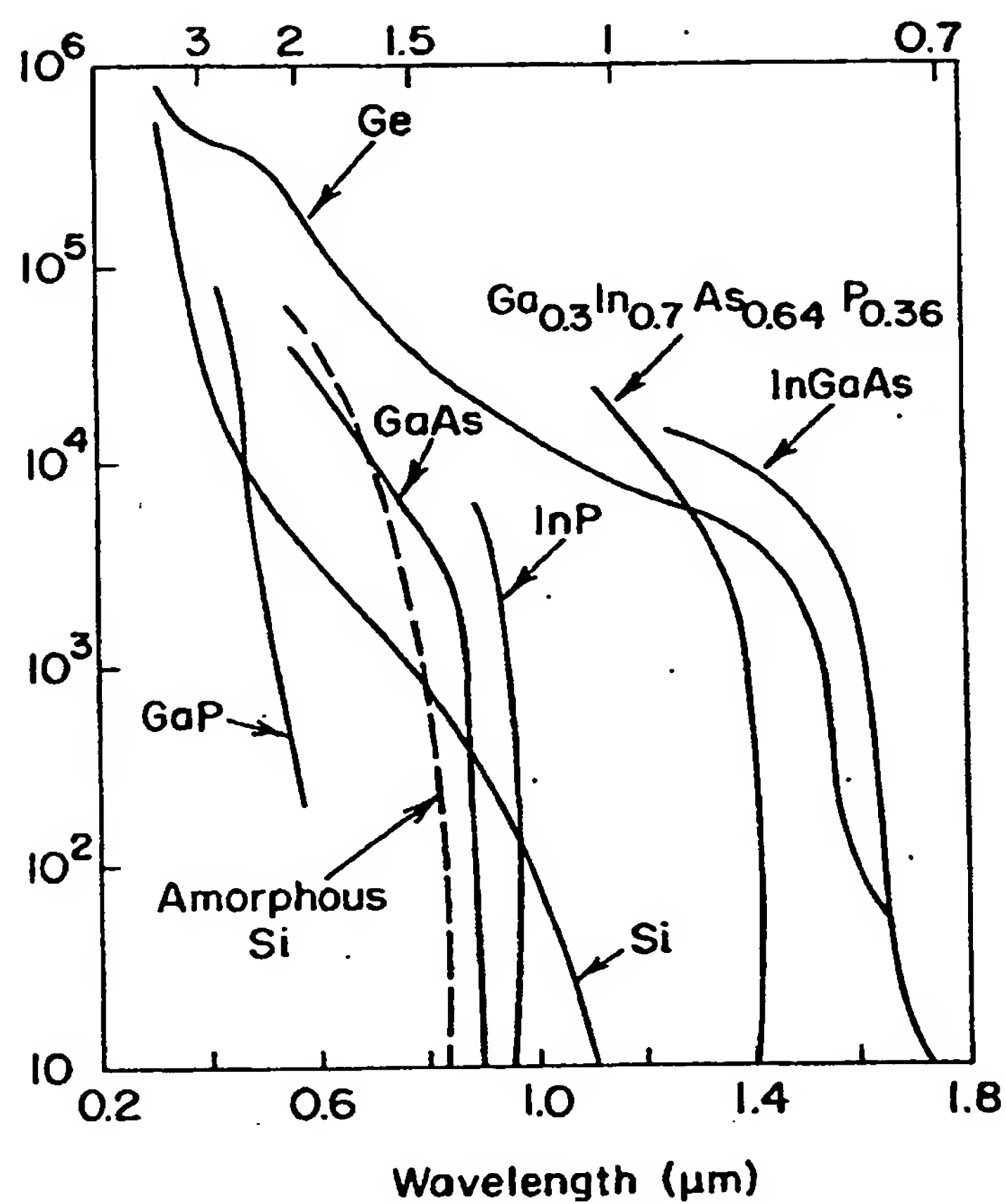
2   a Mach-Zender structure.

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FIG. 1A

FIG. 1B

FIG. 1C

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FIG. 2A

FIG. 2B

FIG. 3

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Light
Input
Side Veiw

Output

FIG. 4A

Top View

FIG. 4B

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FIG. 5A

Ring is non absorbing

FIG. 5B

Ring is absorbing

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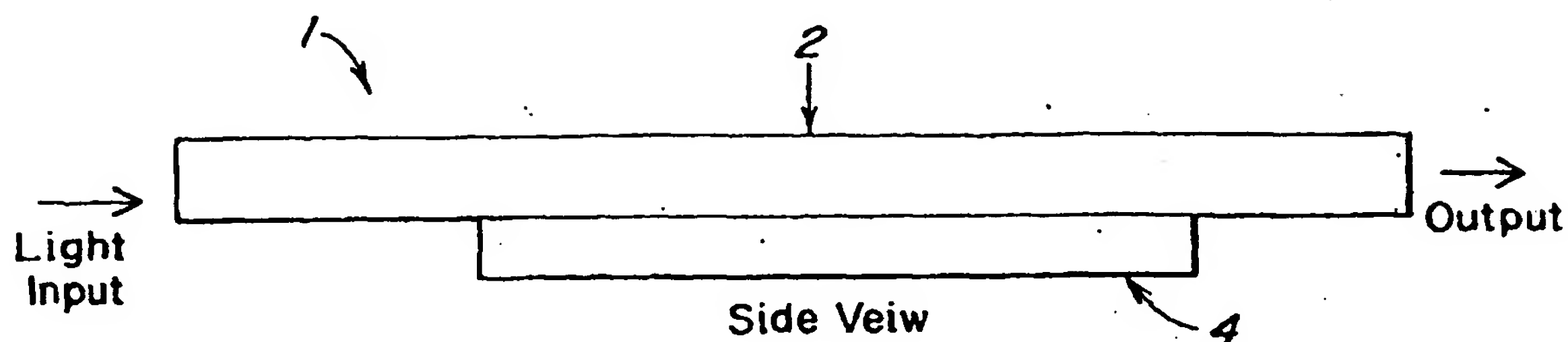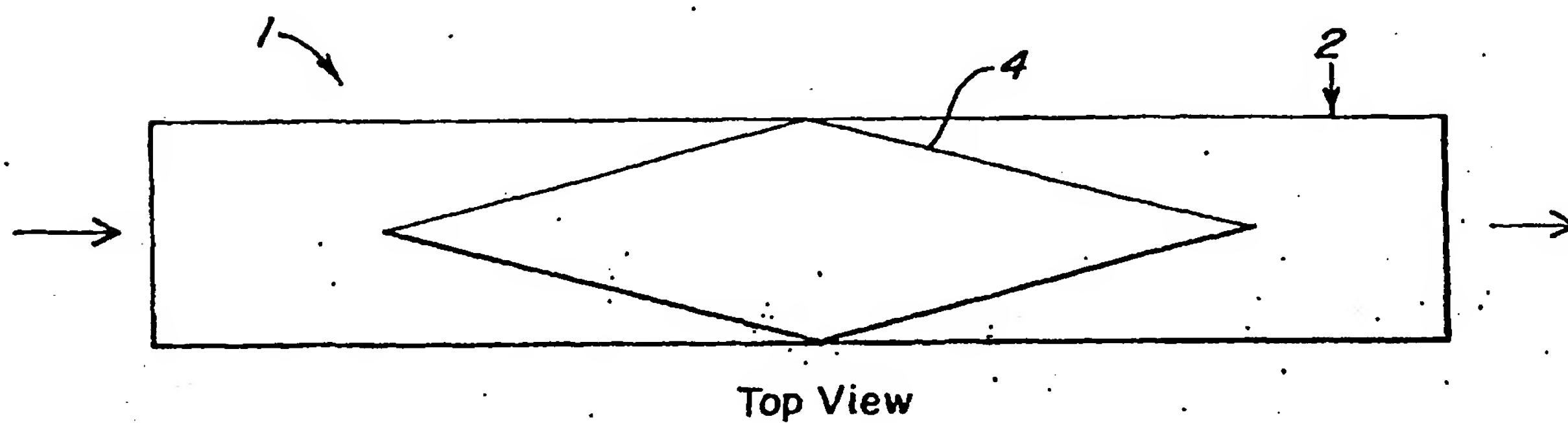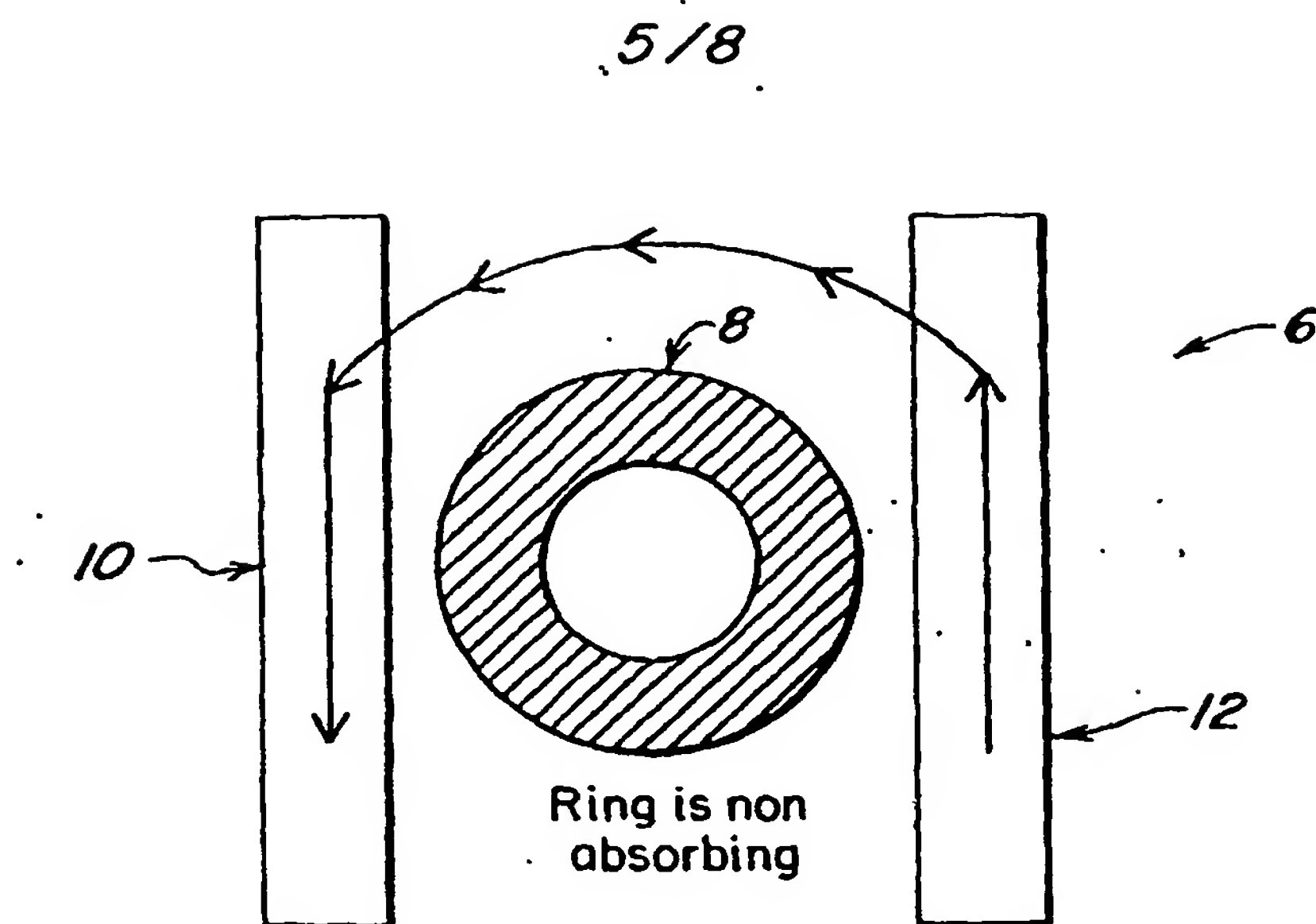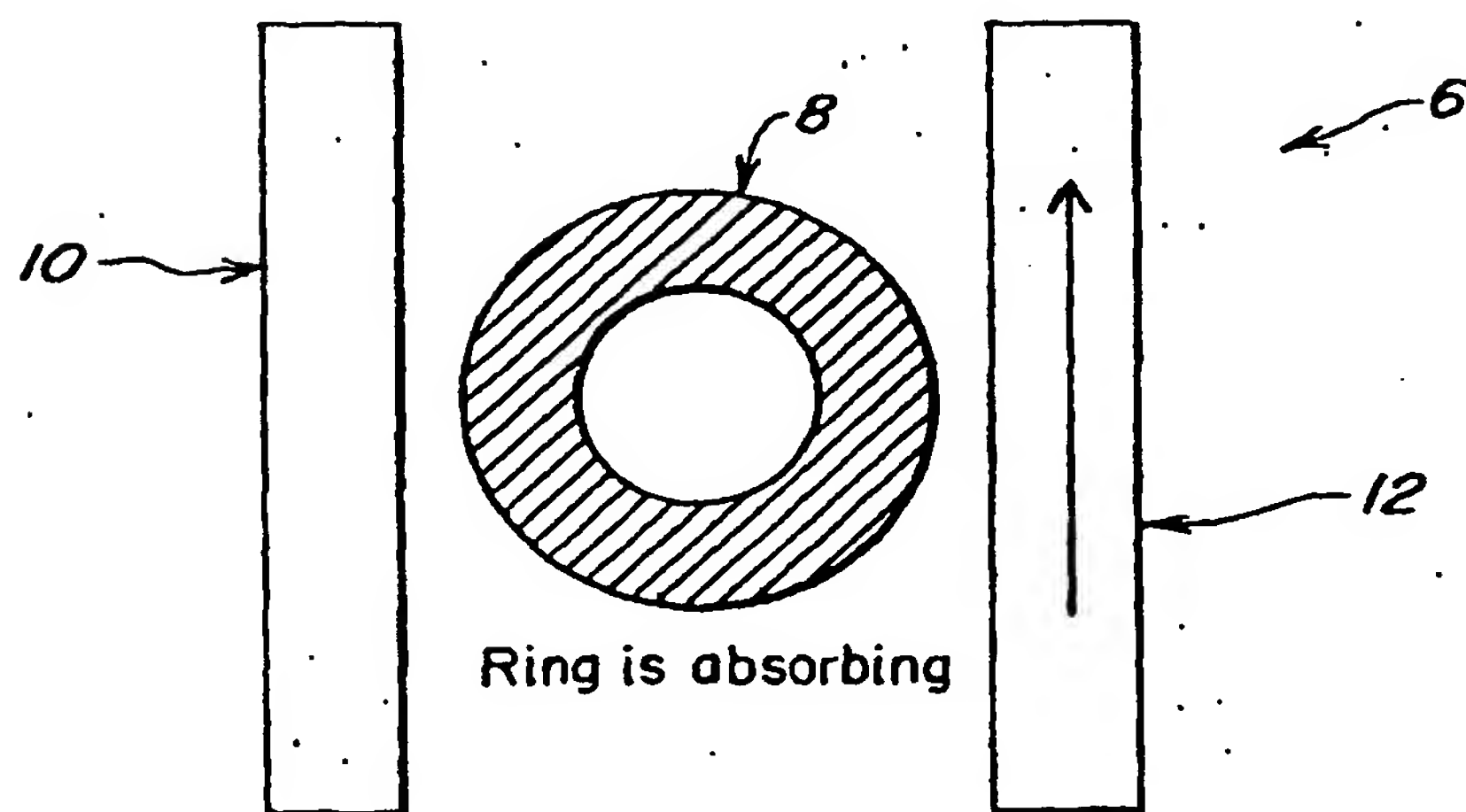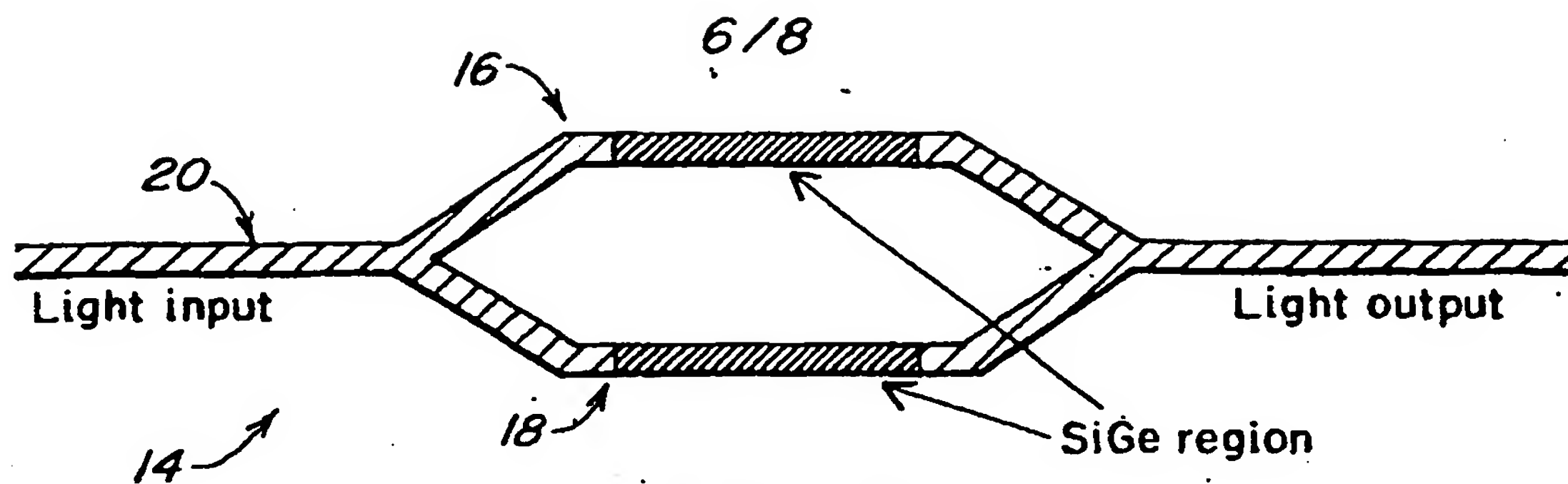
FIG. 6

FIG. 7A

FIG. 7B

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FIG. 7C
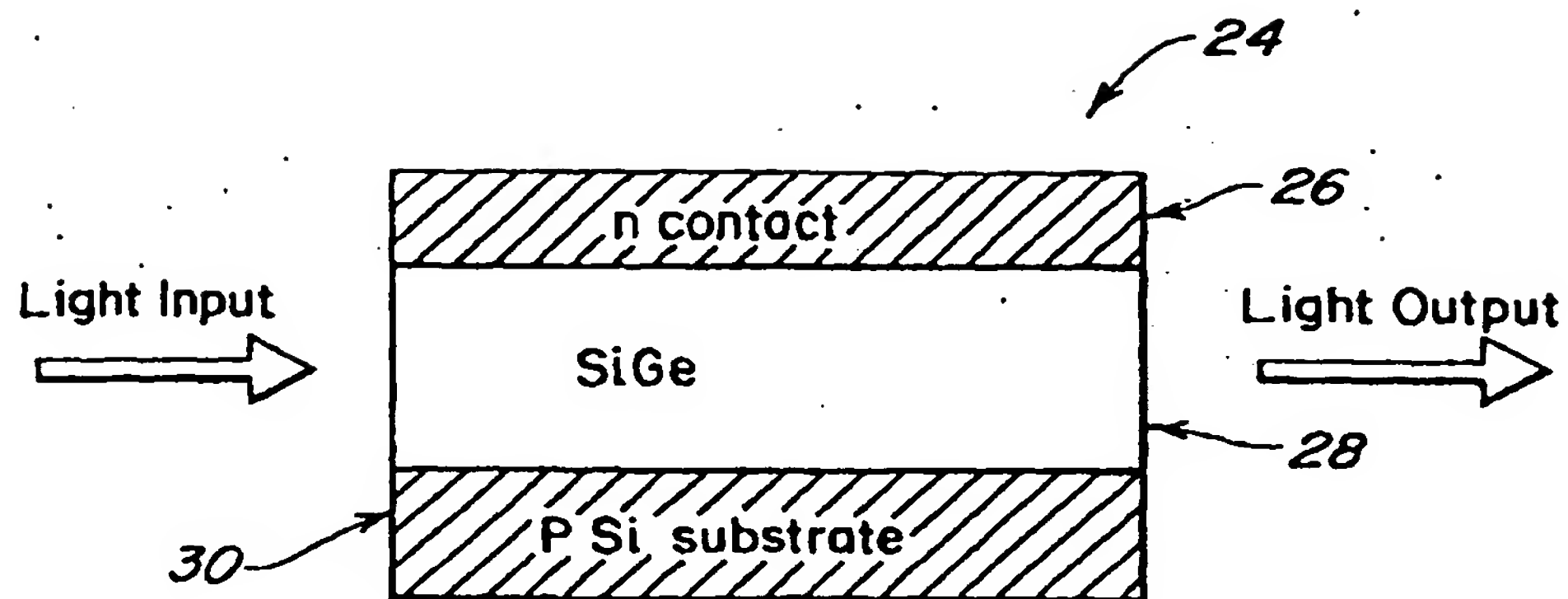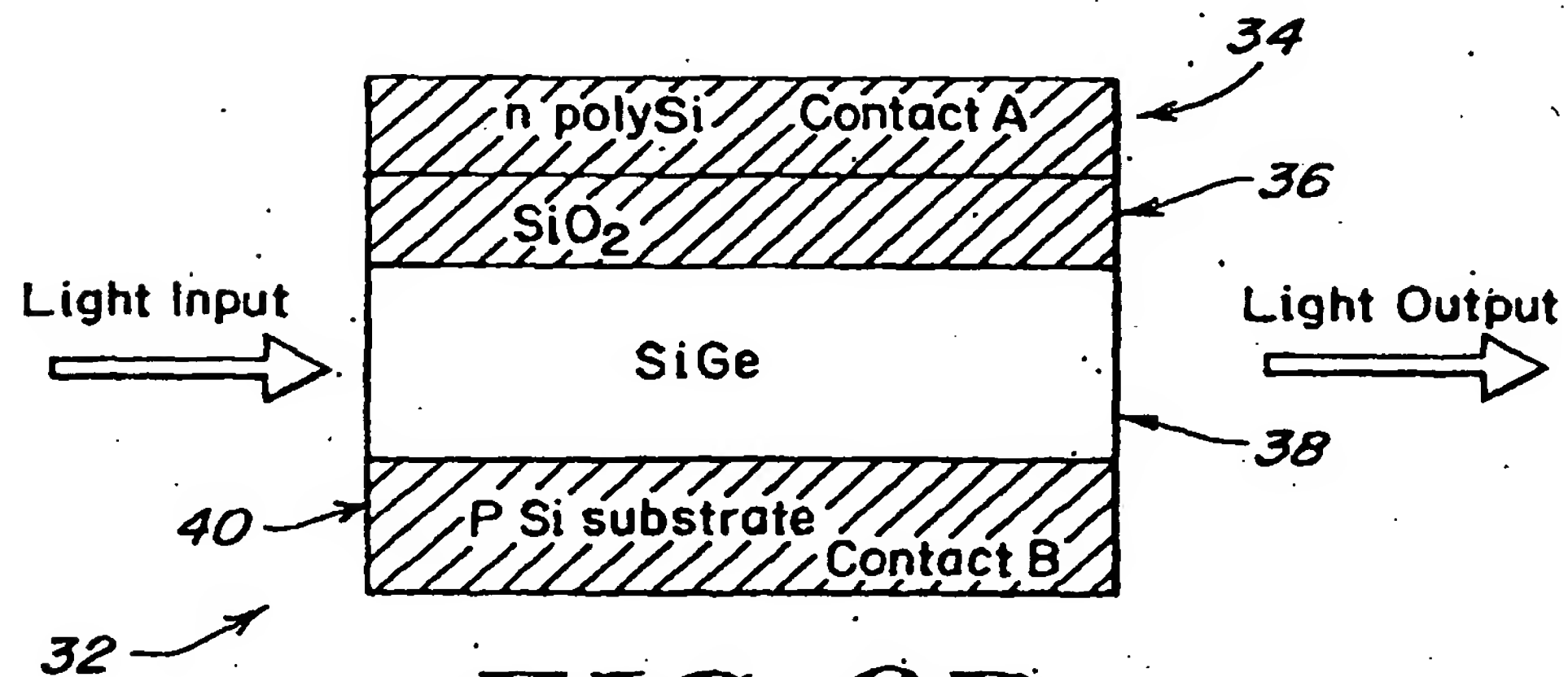
Light Input →

n contact — 26

SiGe

28

P Si substrate

30

Light Output →

24

FIG. 8A

Light Input →

n polySi   Contact A — 34

SiO₂ — 36

SiGe

38

P Si substrate   Contact B

40

32

Light Output →

FIG. 8B

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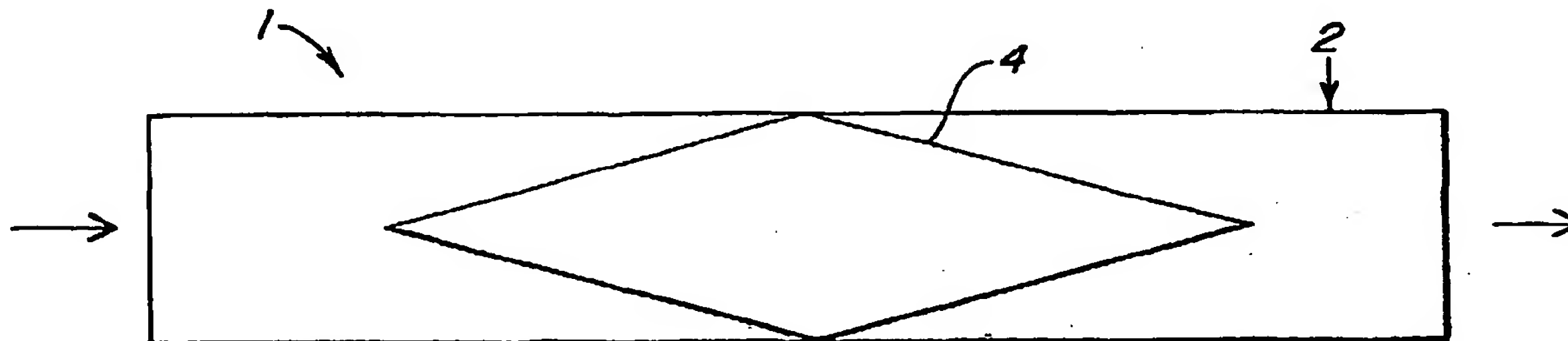
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LIGHT MODULATION USING THE FRANZ-KELDYSH EFFECT

Top View

(57) Abstract: An optical modulator (1) includes at least one waveguide medium (4) that receives light. An absorption medium absorbs the light under predefined conditions and outputs optically modulated light. The absorption medium is comprised of a Ge-based structure. The Ge-based structure uses the Franz-Keldysh effect to create said optically modulated light.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G02F1/17

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 221 053 A (GEN ELECTRIC CO PLC) 24 January 1990 (1990-01-24) claim 2; figure 2 ---	1,18
A	US 5 165 105 A (HAASE MICHAEL A ET AL) 17 November 1992 (1992-11-17) claim 1; figure 1 -----	1,18

[ ] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
2 April 2003	15/04/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gill, R

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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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			JP	6509428 T	20-10-1994
			WO	9303411 A1	18-02-1993

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